Using evolutionary algorithms to optimize office buildings facade

Βελτιστοποίηση προσόψεων κτιρίων του τριτογενούς τομέα με χρήση εξελικτικών αλγορίθμων

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Abstract

Σκοπός της παρούσας έρευνας είναι να διαπιστωθεί η επίδραση των γυάλινων προσόψεων και συστημάτων σκίασης σε σχέση με την ενεργειακή ανάγκη του κτιρίου και η αξιολόγηση της επίδρασής τους στην ενεργειακή απόδοση των κτιριακών εγκαταστάσεων του τριτογενούς τομέα στην Ελλάδα.
Το γενικό πλαίσιο αυτής της μελέτης εξετάζει τη θερμική απόδοση των γυάλινων προσόψεων σε συνδιασμό με συστήματα σκίασης,των κτιρίων.Η μελέτη επικεντρώνεται στην ενεργειακή ζήτηση θέρμανσης,κλιματισμού,φωτισμού.Γι'αυτό γίνεται μελέτη διαφορετικών υαλοπινάκων (με διαφορετικά χαρακτηριστικά Uval, Gval, Tvis) σε συνδιασμό με διαφοτερικά συστήματα σκίασης στον βέλτιστο προσανατολισμό.Το προς μελέτη κτίριο είναι ένα ορθογώνιο κτίριο γραφείων στην Αθήνα (Β κλιματική ζώνη).Τόσο τα αποτελέσματα όσο και η διαδικασία της παραπάνω μελέτης θα εστιάσουνε στη βελτιστοποίηση της ενεργειακής απόδοσης του κτιρίου με την εγκατάσταση της κατάλληλης γυάλινης επιφάνειας (τύπος και μέγεθος),συστήματος σκίασης και τον βέλτιστο προσανατολισμό.
Η ανάλυση επικεντρώνετε στην εύρεση ενός τρόπου βελτίωσης της ενεργειακής απόδοσης ενός κτιρίου ως αποτέλεσμα της ενεργειακής του ζήτησης.Η ανάλυση αυτή είναι γίνεται με βάση τον Κανονισμό Ενεργειακής Απόδοσης Κτιρίων (ΚΕν.Α.Κ.) που είναι σε εφαρμογή από το 2008.Η παρούσα έρευνα δεν είναι σε καμία περίπτωση έρευνα με σκοπό της εύρεση νέων τύπων γυάλινων επιφανειών ή τη δημιουργία νέων σχεδιαστικών προτύπων για κτίρια.Αντίθετα, επικεντρώνεται σε ήδη υπάρχοντα κτίρια γραφείων κοινού σχήματος.

The aim of this research is to identify the main impacts of glazing facades and shading devices in relation to the energy demand of the buildings and to evaluate their contribution to the energy performance in the tertiary sector in Greece.
The context of the research examines the thermal performance of the glazing façades combined with shading devices of buildings. The research focuses on the energy demand of buildings for heating, cooling and lighting. For this reason the evaluation of various glazing types (with different thermal characteristics) in combination with different shading devices at the optimum orientation will be carried out. The type of building that will be used for the aforementioned evaluation (with the use of the software tool, EnergyPlus and optimization tools JEPlus and jEPlus+EA) will be a rectangular shaped office building. The results of this evaluation will be presented and the investigation will be focused on how to improve the energy performance of the building by installing the appropriate type of glazing,shading device at the optimum angle of building oreintation,in combination with the appropriate percentage of glazing area .
The analysis concerns finding a way through which there will be an improvement in the energy performance of a building and as a result reduction of its energy demand. The aim of the investigation is towards the regulation of building energy performance that has been in force since 2008. The present research effort will not try to develop new advanced glazing types nor to create new building design. Instead, the focus will be on existent types of glazing for common office building shape.In the end several examples of fuzzy logic applications are presented.

Acknowledgments

I would like to thank my advisors Aris Tsangrassoulis and Catherine Housti for their help and guidance during the development of my thesis. Also I would like to thank Dr. Yi Zhang and Dr. Ivan Korolija for the development of the optimization tools (jEPlus and jEPlus+EA).Also I would like to thank Dimitrios Zimeris for helping me get my thesis theme.

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Abbreviations

ACH Air Changes per Hour
BAU Business As Usual
Btu/hr*ft^2*°F Btu/(hr*ft^2*°F) (1 Btu/(hr*ft^2*°F) = 5.6782 W/(m2K)) **CIE** International Commission on Illumination
EC European Commission
EN European Standard
EPBD Energy Performance of Buildings Directive
EPS Expanded Polystyrene
EU European Union
HVAC Heating, Ventilation and Air Conditioning
IEA International Energy Agency
MJ Megajoule
IEA International Energy Agency
MS Member States
Mtoe Megatons of oil equivalent (1 Mtoe = 41.87 PJ = 41.87*10^9 MJ)
LSG Light-to-Solar-Gain
NEGAJOULES Avoided energy consumption through savings
R&D Research and Development
SC Shading Coefficient
SHGC Solar Heat Gain Coefficient
Tv Visual transmittance

Chapter 1

Introduction

While most existing EU and national building regulations prescribe requirements only for reducing heating needs,the new EU Directive on the Energy Performance of Buildings requires them to be updated and to also account for the cooling needs. In particular, the EPBD stresses the need to effectively promote the use of passive cooling measures.
The building sector both residential and non-residential (namely tertiary) cover a share of 40% of the total energy demand in the Community.In EU southern countries such as Greece cooling needs occupy big portion of the total energy consumption of buildings.
Non-residential buildings and primarily office buildings are classified among the buildings presenting the highest energy consumption. Energy in office buildings is consumed mainly for heating, cooling, and lighting purposes, while a significant portion is devoted to the consumption of office equipment.
New building technologies and international architectural styles and trends, which promote the use and in some cases even the abuse of poorly shaded glazing façades and lighter construction materials,cause a generalized tendency for summer indoor overheating, even in the colder climates where,typically, such problems never occurred.

The overall building performance depends on various parameters such as:

- Climatic conditions (solar radiation, external air temperature,relative humidity etc).
- Geometric characteristics (orientation, floor plans, dimensions etc)
- Building use data (profile of use, such as the number of operating hours, the number of occupants etc)
- Thermal and optical characteristics of building materials and systems (transparent and opaque building products such as walls, floors, windows etc)

Few building systems affect the overall value of a building as much as glazing does. The building attributes that glazing can affect include:

- Exterior aesthetics
- Indoor views

- Occupant visual comfort
- Occupant thermal comfort
- Annual energy costs, and
- The size and form of HVAC systems

In short, good glazing selections can make buildings more attractive, more comfortable, more productive, and less expensive to own and operate. Over the course of the last few decades glazing technology has improved significantly, greatly expanding designers' options to offer more value to their clients.
For example, glazing is now better able to:

- Let in visible portions of the solar energy while reflecting the non visible energy that can add unwanted heat to a building
- Block out unwanted elements of the outdoor environment, including heat, cold, noise, and glare

The best glazing selection for any given application often depends on local climate, orientation, shading, and interior space usage. Secondly, these advanced glazing technologies cost more at first than the old standbys. To have a complete picture of their true lifetime cost, one must account for the way they reduce both annual energy costs as well as the first costs of HVAC systems. (Southern California Edison, 2000).
Taking into consideration the aforementioned, the reduction of energy demand of buildings can be achieved through the optimisation of building performance. One of the most important factors which contribute to the building performance is the application of energy efficient building products and their optimal combination to the building envelope. Specifically, the impact of transparent building components, namely glazing is very crucial to the energy demand of buildings.
Due to the large portion of glazing surfaces to the overall building façades, the need for their effective application is evident especially in countries like Greece where cooling needs are increased.

1.1 Research problem and/or hypothesis

The research problem of this study is to optimize the glazing façade of buildings in terms of energy saving of the tertiary sector of Greece. Taking into consideration the increased energy consumption of buildings in Greece, it is made clear that the improvement of the energy performance of a building can be achieved by the effective application of glazing in the building envelope. The answer to the research problem will be the potential energy saving of buildings by the application of appropriate type and percentage of glazing per building façade orientation.

1.2 Justification of the research (including aims)

"The residential and tertiary sector, the major part of which is buildings, accounts for more than 40% of the final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also

its carbon dioxide emissions." (European Commission, 2002).
Thermal building regulations in Europe, inspired by the first oil crisis of the decade 1970, only concerned the reduction of winter heating needs. During that period, cooling needs were not a major issue. Both residential and non residential buildings used mostly old traditional construction methods, well suited for avoiding overheating in most of Europe, and internal gains were modest, as electricity-using equipment and lighting were used in a modest way.
The focus on reducing energy consumption for heating - thus paying less for heating bills - was such that errors were made, namely the effort to increase air-tightness of the building envelope without care to provide sufficient ventilation by natural (i.e. glazing openings) or mechanical means resulted in indoor air quality problems.
New building technologies and international architectural styles have caused a tendency for summer overheating, even in colder climates where, typically, such problems had never taken place before then. The use and abuse of poorly shaded glazing façades and lighter construction materials are the main parameters which resulted in this. However, most of the building regulations up to the early 1990's continued to ignore this issue and only two countries, France and Portugal, introduced summer comfort requirements in building design around 1980. (Maldonado, 2005).
A more recent survey of European building regulations - completed within the EC-supported SAVE project ENPER-TEBUC - shows that the situation has much improved now, but still the number of European countries which have included in their building regulations specific summer requirements is quite small. (Maldonado, 2005)
In 2002, the Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings enforced the improvement of building energy performance taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.
In accordance with the aforementioned Directive, the energy performance of a building is the amount of energy actually consumed or estimated to meet the different needs associated with a standardized use of the building, which may include, inter alia, heating, cooling, ventilation and lighting. This amount shall be reflected in one or more numeric indicators which have been calculated, taking into account insulation, technical and installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighbouring structures, own-energy generation and other factors, including indoor climate, that influence the energy demand.
It is noted, that energy consumption in the building sector can be significantly reduced by improving the overall energy intensity. It is important to adopt a global approach and to integrate measures of rational use of energy for the building envelope. (European Commission, 1997).
Building design is a complicated process during which critical decisions concerning the different systems related to the building are made at an early stage.
In the last few decades, many architects and building designers have laid more emphasis on the "lightness" and the "transparency" of buildings, urging towards fully glazed façades. (Butera, 2005).
Large glazing façades especially in non - residential buildings are applied for the utilization of daylight. This results in reduction of the electricity consumption for lighting but also in high cooling demand if excessive solar gains are achieved in the interior.

This architectural style in combination with poorly shaded glazed façades has caused a generalized tendency for summer overheating, even in the colder climates where, typically, such problems had never taken place before then. (Maldonado, 2005).
Since the energy performance of buildings and consequently their energy consumption is also affected by the building design along with the products' characteristics, the selection of the most appropriate building products such as windows namely glazing systems is very crucial. (Pérez-Grande et al. 2005).
Taking into consideration the above and in line with the aim of this research, various glazing types will be assessed in order to identify their contribution to the energy demand of office buildings in Greece.
The type of building that will be used for the aforementioned evaluation (with the use of the software tool, EnergyPlus) will be a rectangular shaped office building. The building is a middle-size office building with office modules aligned on two façades, separated by a central corridor.The part of the building that all experiments were applied is being depicted below.Specifically we have assumed that every surface of our test office is adiabatic expept the walls with window which are exposed to air.

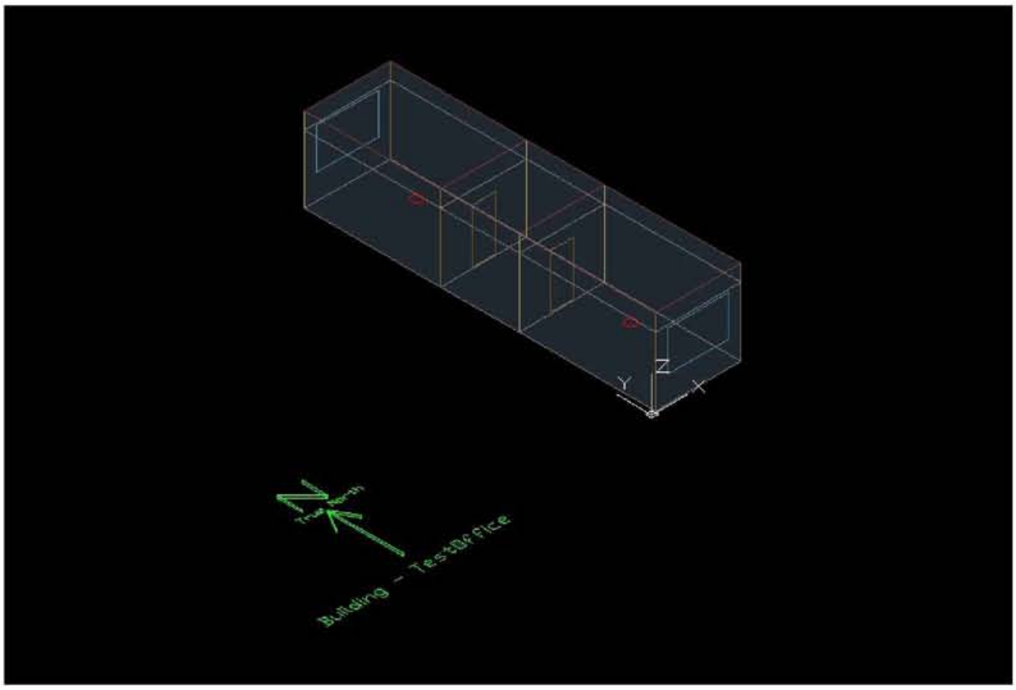


Figure 1.1: Test office

According to the European Standard EN 572-9:2004 the thermal transmittance (U value) comprises the thermal property of the glass which affects the thermal performance of the building. Therefore this value will be the main parameter for the aforementioned assessment of glazing façades to the energy performance of office buildings.

Greece is divided in four climatic zones (Figure 1.2) and since the climatic conditions comprise one of the main factors which contribute to the building performance, the evaluation will be carried out for Athens (Climate Zone B).

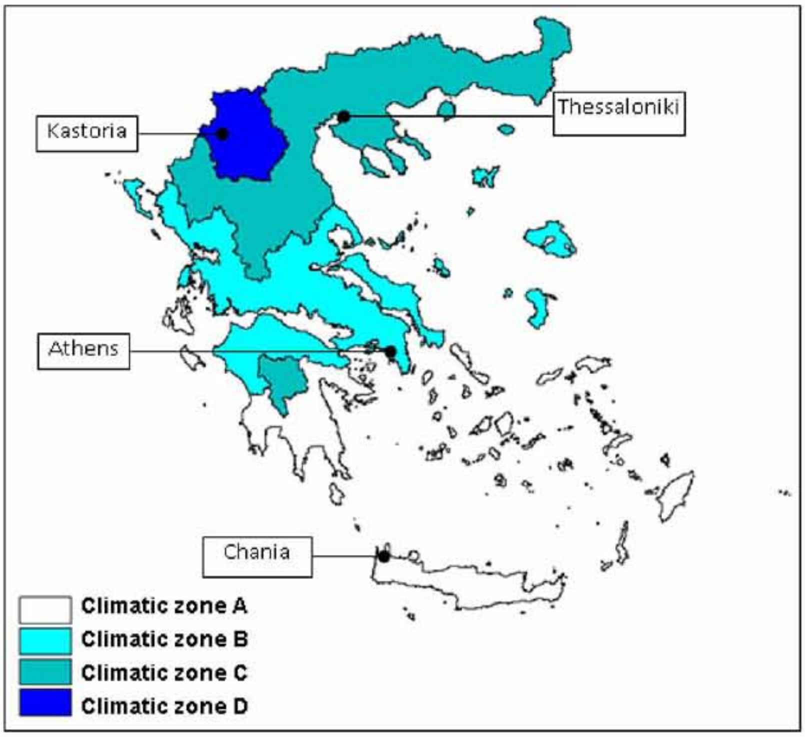


Figure 1.2: Climatic zones in Greece

1.3 Methodology

The aim of methodology is to help us to understand, in the broadest possible terms,not the products of scientific inquiry but the process itself.
The research will not try to re-appraise any existing theory that leads to reduced energy demand from the application of improved glazing in the buildings nor to modify or to re-interpret them from a different point of view. Therefore the review approach does not fit as the appropriate research method; instead the empirical approach will be adopted for conducting the research.
Empirical research methods are a class of research methods in which empirical observations or data are collected in order to answer particular research questions. While primarily used in academic research, they can also be useful in answering practical questions. [MON].
The methodology that will be followed is based on hypothesis in the form of 'what if'. The examination of specific parameters (i.e. different building orientations, different glazing types etc) and the analysis of the outcomes constitute some of the research questions. Therefore the deductive research will be applied.
Deductive reasoning works from the more general to the more specific. Sometimes this is informally called a "top-down" approach (Figure 1.3). One might begin with thinking up a theory about our topic of interest. One then narrows that down into more specific hypotheses that one can test. One narrows down even further when one collects observations to address the hypothesis in the form of 'what if'. This

ultimately leads one to be able to test the hypothesis with specific data - a confirmation (or not) of the original theories. [RMKB].

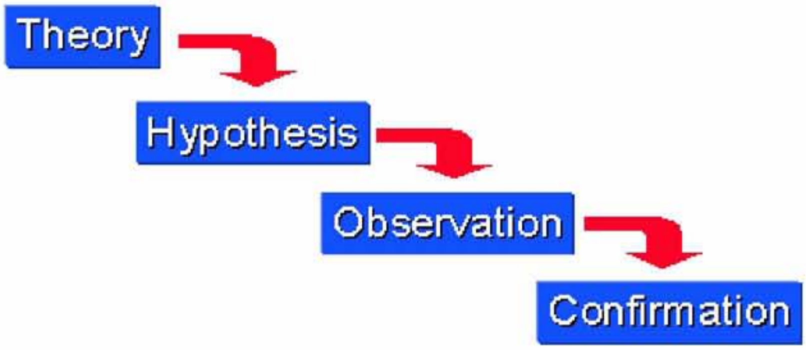


Figure 1.3: Deductive research

The main objective of the research is the evaluation of simulation results. Therefore the type of design will be experiment. A prototype building will be used in order to carry out the simulations. Various types of glazing in combination with different shading devices at the optimum orientation will be examined in order to identify their effects on the energy performance of the building.
An experiment involves making a change in the value of one variable – called the independent variable – and observing the effect of that change on another variable – called the dependent variable. (Cohen et al. 2000).

1.4 Delimitation of scope

This research study concerns the thermal simulation analysis of buildings by the use of software (EnergyPlus,jEPlus,jEPlus+EA). It attempts to simulate the thermal building performance using different types of glazing for shading devices at the optimum orientation.The analysis has been focused on the buildings of the tertiary sector (office buildings) leaving the residential buildings out of the scope. In addition, economic issues are not examined. This is due to short time available for the enquiry and due to the need for a more focused research.

1.5 Outline of the dissertation

In the first chapter, an introduction about this study is presented. The reader is introduced to the context of the research and the research problem is defined. The aims of the research are outlined and a justification for attempting the research study is also given. In addition, the methodology that has been chosen for conducting the research is described.
In the second chapter, the research is defined by means of analysing the practical

and theoretical problems. Within the framework of the practical problem, the need for the reduction in the energy demand and the potential of energy saving in the building sector are presented, whilst the theoretical problem deals with the current situation about the energy consumption in the building sector and the lack of knowledge of the use of glazing façades in buildings. The research problem is defined along with the research questions, so as to overcome the research problem.
The third chapter includes the research process plan in which the steps that will be followed during the research are presented.
The fourth chapter includes the building parameters that will be used for the simulations. Specifically the wall type, the glazing properties, the different shading devices the optimum angle orientation and all the relevant parameters are presented so that we have a comprehensive description of the building and its parameters that will be examined. The analysis concerns the simulations' outcomes and the potential energy saving is analysed. Findings are presented in tabulated form and figures.

1.6 Summary

The current situation about the energy consumption in the building sector in the EU was introduced in this chapter. Non-residential buildings and primarily office buildings are classified among the buildings presenting the highest energy consumption. Glazing façades contribute significantly to the building energy performance and this is the starting point for conducting the present study. Based on this, the research problem is defined, that is the optimization of glazing façade towards energy saving. The methodology that will be followed was also presented.

Chapter 2

Research definition

2.1 Introduction

The practical and theoretical problems are defined in this chapter. The main issues presented in the section of the practical problem are related to the need for the reduction of the energy demand in the building sector, and the effects of the glazing façades on the building performance. The theoretical problem concerns the need for energy saving, the contribution of the building sector to the energy consumption and the way this can be reduced through the installation of appropriate glazing types and areas in the building. In addition, the research questions are presented.

2.2 The practical problem

The problem environment: The need for the reduction of the energy consumption in the building sector

One of the main energy R&D (Research and Development) priorities in Greece is the control of the energy consumption in the building sector and compliance with the EPBD,including technologies of "energy optimised buildings" and active renewable based systems for heating and cooling. These priorities were expressed during the consultation for the thematic priorities of the European Framework 7 Programme and they will be unchanged in the short-medium and medium-long term of the research programme. (IEA,2006).
Based on a study carried out by Cartalis et al. (Cartalis et al., 2001), there is a decrease in energy consumption for heating and an associated increase in energy consumption for cooling. The climate changes in the south-eastern Mediterranean (Greece) were simulated for the year 2030 on the basis of specially constructed climatic scenarios which describe potential reductions in the emissions of greenhouse gases, and were, thereafter, used to calculate the heating and cooling degree days for the same year. The results showed that the cumulative amount of heating and cooling degree days will decrease and increase, respectively, as compared to the respective amount for the year 1990. The relative differences in energy consumption for heating and cooling are presented in the following table (Table 2.1):

Climate simulation scenario	Relative difference of energy consumption for heating in comparison with BASE CASE(%)	Relative difference of energy consumption for cooling in comparison with BASE CASE(%)
BASE CASE (today's climatic situation)	0	0
Business As Usual	-10	+28.4
Simulation 1	-8.4	+23.4
Simulation 2	-7.5	+21.4
Simulation 3	-6.4	+18.9
Simulation 4	-4.7	+14.9

Table 2.1: Relative differences in energy consumption for heating and cooling. (Source: Cartalis et al., 2001).

The problem context: The potential of energy saving in the building sector and the need to meet the requirements in view of the implementation of the Directive 2002/91/EC (Energy Performance of Buildings Directive, EPBD)
According to the Action Plan for Energy Efficiency (Commission of the European Communities, 2006) the European Union is facing unprecedented energy challenges resulting from increased import dependence, concerns over supplies of fossil fuels worldwide and a clearly discernable climate change. In spite of this, Europe continues to waste at least 20% of its energy due to inefficiency. The EU can and must lead the way to reducing energy inefficiency, using all available policy tools at all levels of government and society.

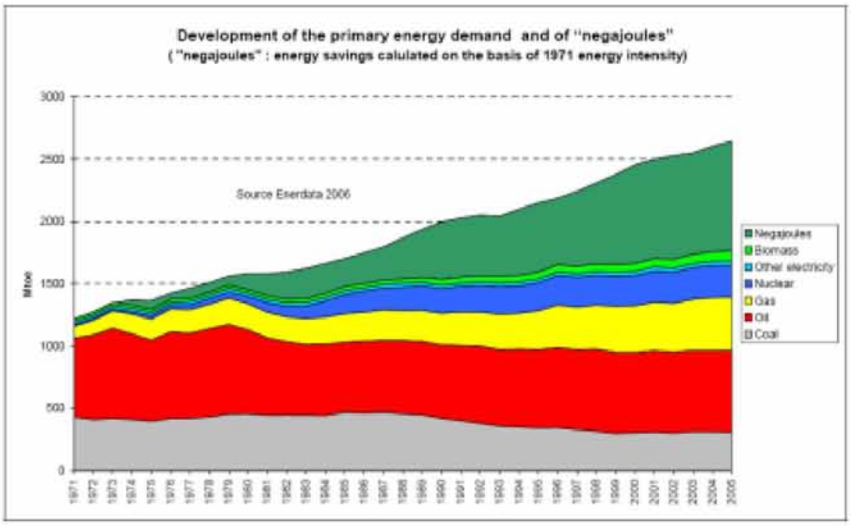


Figure 2.1: Development of the primary energy demand and of "negajoules". (Source: Commission of the European Communities, 2006).

Even though energy efficiency has improved considerably in recent years,it is still technically and economically feasible to save at least 20% of total primary energy by 2020 on top of what would be achieved by price effects and structural changes in the

economy, natural replacement of technology and measures already in place. Partly because of its large share of total consumption, the largest cost-effective savings potential lies in the residential (households) and commercial buildings sector (tertiary sector), where the full potential is now estimated to be around 27% and 30% of energy use,respectively.In residential buildings, retrofitted wall and roof insulation offer the greatest opportunities, while in commercial buildings,improved energy management systems are very important.
The problem of interest: How the glazing façade can be optimized for the energy performance of buildings
Few building systems affect the overall value of a building as much as glazing does. (Southern California Edison, 2000). The building attributes that glazing can affect include:

- Exterior aesthetics
- Indoor views
- Occupant visual comfort
- Annual energy cost
- The size and form of HVAC systems.

In short, good glazing selections can make buildings more attractive, more comfortable, more productive, and less expensive to own and operate.Over the course of the last few decades glazing technology has improved significantly, greatly expanding designers' options to offer more value to their clients.

For example, glazing is now better able to:

- Let in visible portions of solar energy while reflecting the non visible energy that can add unwanted heat to building.
- Block out unwanted elements of the outdoor environment,including heat,cold,noise and glare

For designers to effectively specify glazing, they need to have a good understanding of not only how a given glazing system transmits visible light, but also what portion of the sun's total spectrum provides heat to the interior (see Figure 2.2).

The characteristics of glazing systems are typically expressed using the following technical terms:

- U-value (also known as U-factor) expresses how much energy a glazing system transfers by conduction and convection. The lower the U-value, the more resistance a glazing system poses to heat transfer. Single-glazed units are the worst-case; their U-values are typically higher than 1.0 Btu/(hr*ft^{2}*°F) (5.68 W/(m^2K)), whereas double-glazed units with well-designed frames have U-values of less than 0.5 Btu/(hr*ft^{2}*°F) (2.835 W/(m^2K)).

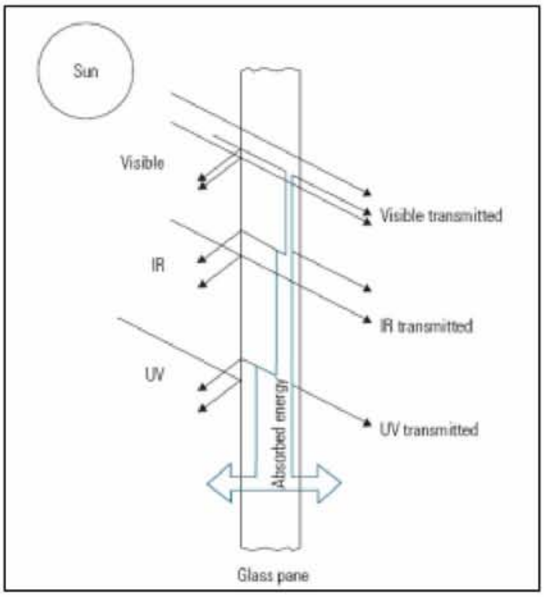


Figure 2.2: Heat and light reflectance and transmission. (Source: Southern California Edison, 2000).

- Solar heat gain coefficient (SHGC) and shading coefficient (SC) are both measures of a glazing system's net solar gain. SHGC, which is the more modern index, is the sum of the solar radiation transmitted through the glazing and the portion of absorbed energy that ends up supplying heat inside. Glazing systems with high SHGCs (0.7 to 0.9) provide substantial solar gain, whereas those with low values (0.2 to 0.4) provide little solar gain. The SC expresses the net solar energy delivered by a given glazing system in relation to how much is transmitted through clear float glass 1/8 inch thick under the same circumstances.

- Visual transmittance (Tv) is a measure of the proportion of visible light that passes through a glazing system. Glazing systems with high values of Tv (0.7 to 0.9) provide lots of natural light and good vision, but they can also be a source of unwanted glare if not properly controlled. Systems with lower values of Tv (less than 0.4) can be visually distorting and quite gloomy on cloudy days

- The light-to-solar-gain (LSG) ratio is simply Tv divided by SHGC. The LSG ratio is a useful index to compare how much light (and visibility) a glazing system provides in proportion to how much solar gain it produces. Systems with an LSG ratio greater than 1 provide more light than heat.

There are many more choices on the designer's palette than ever before, and the potential combinations are virtually endless. Glazing may be clear, tinted, coated, or filmed – or a combination of these options. Windows may be single - or multiple paned, and the multiple-paned units can be filled with air or inert gas. Thermal breaks that improve the performance of the windows at their edges are also available. The materials, the techniques used, and the degree to which various treatments are applied ultimately determine the key characteristics of each glazing unit.

2.3 The theoritical problem

The subject: Energy saving According to the Green Paper on Energy Efficiency (Commission of the European Communities, 2005), the European Union has to strongly urge towards a re-invigorated programme promoting energy efficiency at all levels of European society.
Energy saving is without doubt the quickest, most effective and most cost-effective way of reducing greenhouse gas emissions, as well as improving air quality, particularly in densely populated areas. It will therefore help Member States to meet their Kyoto commitments. Secondly, it will constitute a major contribution to the longer term EU efforts on combating climate change through further emissions reductions.Many developing countries fully recognise the essential role of energy efficiency in addressing these multiple challenges.
For the EU, the cost-effective saving of energy means lower dependence on imports from third countries, greater respect for the environment and reduced costs for the EU economy. Reducing energy needs is hence a policy objective which would contribute to the objectives of the Lisbon agenda by boosting the European economy and creating new jobs. Energy-efficiency policy also brings significant savings on household energy bills and thus has a direct impact on the everyday lives of all European citizens. (Commission of the European Communities, 2005).
The implementation of the Directive on the energy performance of buildings (EPBD, 2002/91/EC), as from 2006, will permit a gain estimated at some 40 Mtoe (Megatons of oil equivalent) between now and 2020. (Commission of the European Communities, 2001).
In order for this target to be achieved, several measures have to be taken. One of these measures is the energy savings that can be achieved through the improvements of the building envelope.

The area: Energy consumption in the building sector

Energy consumption is a major contributor to climate change, which is the cause of increasing concern over recent years. Energy is the source of 4/5 (78%) of the total greenhouse gas emissions in the EU. (Commission of the European Communities, 2005).
The residential and tertiary sector, the major part of which is buildings, accounts for more than 40% (see table-figure 2.3) of the final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions. (Commission of the European Communities, 2002). Space heating is by far the largest energy end-use of the tertiary sector in Member States (52%), while energy consumption for lighting and "other" (which is mainly office equipment) is 14% and 16% respectively. Water heating, cooking and cooling make up 18% of the sector's total energy consumption (see Figure 2.4).

2002	Buildings (residential and tertiary[1])		Industry		Transport		All final demand sectors	
	Mtoe	% of final demand	Mtoe	% of final demand	Mtoe	% of final demand	Mtoe	% of final demand
Solid fuels	12.2	1.1	38.7	3.6	0.0	0.0	50.9	4.7
Oil	96.8	8.9	46.9	4.3	331.5	30.6	475.2	43.9
Gas	155.6	12.2	105.4	9.7	0.4	0.0	261.5	24.2
Electricity (incl. 14% from RES)	121.3	11.2	91.2	8.4	6.0	0.6	218.5	20.2
Derived heat	22.8	2.1	7.5	0.7	0.0	0.0	30.3	2.8
Renewables	29.0	2.7	16.2	1.5	1.0	0.1	46.2	4.3
Total	437.8	40.4	306.0	28.3	338.9	31.3	1,082.6	100.0

Figure 2.3: Final energy demand. (Source: Green Paper on energy efficiency or doing more with less, Commission of the European Communities, 2005).

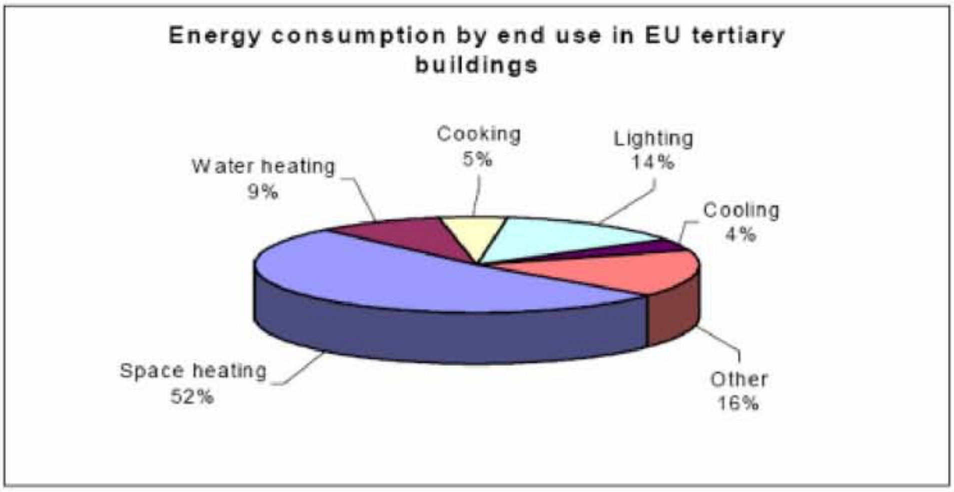


Figure 2.4: Energy consumption in the tertiary sector. (Source: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings, Commission of the European Communities, 2001).

The gap in knowlegde: The lack of knowledge of the use of glazing facades in buildings and the reduction of energy consumption especially during the summer period.

The recent EC Action Plan for Energy Efficiency (i.e. "Realising the potential") which was published in October 2006 identifies energy efficiency in the building sector as a top priority. It has a key role for the EPBD in realising the savings potential in the buildings sector, which is estimated at 28% and which in turn can reduce the total EU final energy use by around 11%. (Commission of the European Communities, 2006).

The EPBD is set to promote the improvement of energy performance of buildings with the following requirements to be implemented by the Member States:

- the general framework for a methodology of calculation of the integrated energy performance of buildings,
- the application of minimum requirements on the energy performance of new buildings,
- the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation,
- energy performance certification of buildings,
- regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old,
- requirements for experts and inspectors for the certification of buildings, the drafting of the accompanying recommendations and the inspection of boilers and air-conditioning systems.

Based on the national report of the implementation of the EPBD in Greece (EPBD Buildings Platform, 2007) there are no calculation procedures adopted yet; they were foreseen to be issued within 2007. Software tools for the assessment of the energy performance of buildings are expected to be developed.
Comprehensive information and detailed data for the non-residential building stock is rather limited, although it is the fastest growing energy demand sector.
In this research, it is attempted to evaluate the effect of glazing façade on the energy performance of the buildings focusing on the tertiary sector, with the use of EnergyPlus,JEPlus and jEPlus+EA software. In order to have an extensive assessment, one type of building will be used (rectangular shaped office building) for optimum orientation, various types of shading devices and different glazing surfaces. This will lead to a detailed assessment of the contribution of the building glazing facades to the energy saving effort; it will provide the basis for assessments of different building products and will enhance our knowledge on the use of glazing façades.

2.4 Research questions and/or hypothesis

1. What are the main EU actions and Directives regarding the energy consumption in the building sector?
2. What is the current situation regarding the energy consumption in the Greek building sector?
3. Which are the main parameters that affect the thermal performance of buildings?
4. How can the reduction of building energy demand be achieved through the application of different types and percentages of glazing per façade orientation?

2.5 Summary

The second chapter was related to the analysis of the practical and theoretical problems. The need for reduction in the energy consumption in the EU was analysed and the saving potential in the building sector was presented. The importance of the glazing façade and how it affects the building energy performance was also described. The answer to the research problem, as defined in section 1.2, concerns the optimization of the glazing façade of buildings in terms of energy saving of the tertiary sector, and is the application of appropriate glazing type,area and shading at the optimum building facade orientation.

Chapter 3

Methodology

3.1 Introduction

In this chapter the research process plan has been developed. The steps that will be followed for the simulation are presented and what it is needed to be done in a logical order so as to reach a final conclusion about the aim of the research problem.

3.2 Research process plan

The research process plan illustrates the main parameters that were used for the building simulation. The research process plan is developed in five main steps:

- Glazing size in the four basic directions (North,East,West,South)
- Type of glazing optimization (Double Clear,Double Solar Control and Double LowE are the types of glazing surfaces that were used in the simulation in order to find the one with the lowest energy consumption)
- Type of external blind optimization for each of the aformentioned glazing surface.The types of blinds used in the simulation are:External Venetian Blinds with Flat slat,External Venetian Blinds with Dim-Out slats and External Venetian Blinds with Beaded Slats.
- Overhangs characteristics optimization in combination with all the afromentioned glazing surfaces and external venetian blinds,and
- Fins characteristics optimization in relationship with all the aformentioned

In order to perform the simulations three software tools were used:EnergyPlus,JEPlus and jEPlus+EA.
EnergyPlus is an energy analysis and thermal load simulation program. Based on a user's description of a building from the perspective of the building's physical make-up and associated mechanical and other systems, EnergyPlus calculates heating and cooling loads necessary to maintain thermal control setpoints, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment. Simultaneous integration of these—and many other—details verify that the EnergyPlus simulation performs as would the real building.
JEPlus is an EnergyPlus simulation manager for parametrics.Parametric analysis

is often needed for exploring design options, especially when a global optimization method is not available, or the optimization result is in doubt. Parametric analysis can also be applied to all design variables simultaneously, which forms an exhaustive search that, on a fine mesh, guarantees the discovery of the global optimum solution. To perform complex parametric analysis on multiple design parameters, a tool is needed to create and manage simulation jobs, and to collect results afterwards. jEPlus has been developed for this purpose.
jEPlus+EA is a tool for building design optimization by using evolutionary algorithms.The concept of jEPlus+EA is using Evolutionary Algorithms search through the design space defined by a jEPlus project. A few rules have to be followed when preparing the project.
The results, which are the outputs from the simulations representing the building energy demand, of each building orientation will be assessed and the optimization of building glazing façade will be achieved.

3.3 Ethical considerations

The present research does not involve other persons in the form of interviews and/or personal data so it doesn't cause any physical or emotional harm to anybody. Additionally, it is not a funded research and it is not needed to use any laboratory infrastructure. It is a technical project conducted in an ethical manner by the researcher. The software tools (EnergyPlus,JEPlus and jEPlus+EA) used by the author are commercial so there is no need for authorization use.
The quality control of the parameters used and the data considered for the simulations was carried out by the professor and hence any suggestions and/or corrections have been considered so as to avoid any ethical problems. The research is considered important since it produces results helpful for the architects, the building designers, and engineers. The implementation of the results will benefit the building users since the research work focused on the reduction of the building energy demand.

3.4 Summary

In the third chapter the research process plan was presented. The steps followed constitute the process to evaluate various glazing types (with different thermal characteristics) in combination with different shading systems per façade, at the optimum orientation and glazing area per facade in order to identify their effects on the energy performance of the building and hence to achieve the minimum building energy demand. The ethical considerations for conducting the research were also presented.

Chapter 4

Analysis and results

4.1 Introduction

In this chapter the assessment of the simulation results is presented. An overview of the parameters concerning the building and the climatic data used for the simulations is also presented. The simulations' outcomes are analysed and the assessment is focused on the minimum energy demand resulting from the application of the aformentioned optimizations.

4.2 Results of analysis:The findings

4.2.1 Definition of parameters

In order to perform the simulations, it is needed to define the following parameters:

- **Climatic Data:** Hourly climatic data (mean hourly data for each month) were taken from the representative meteorological stations of each of the cities examined. Solar radiation, external air temperature, relative humidity, wind speed and ground temperature are the main climatic data input.
  For Athens (B climatic zone) the data from the meteorological Asteroskopio Station of the Hellenic National Meteorological Service has been used.
  The characteristics of Asteroskopio Meteorological Station are the following:
  - Latitude 37°58'
  - Longitude 23°43'
  - Elevation (Station) 107m
  - **Air Temperature:**The mean yearly air temperature is 17.9 °C,with mean minimum temperature of 9.5 °C and mean maximum temperature of 27.7 °C.
  - **Relative Humidity:**The mean annual relative humidity is 60.7%, which is relatively high, ranging from 46.5% to 72.4%.
  - **Solar Radiation:**The mean annual global solar radiation is 129.6 kWh/(m^2*month), whilst the mean annual diffuse solar radiation is 48.1 kWh/(m^2*month)

– **Wind:**The wind speed is moderate – the mean value is approximately 2.4m/sec and the maximum is 2.7m/sec in July. The wind direction is SW during April, May and June and NE for the rest of the months.

- **Geometric data:**As geometric data, dimensions and form of the building have been used according to figure 1.1.For the thermal simulations, three (3) thermal zones have been defined according orientation. In specific, thermal zone 1 includes the offices,thermal zone 2 includes the corridor, thermal zone 3 the wall surface with outside boundary condition set to outdoors.

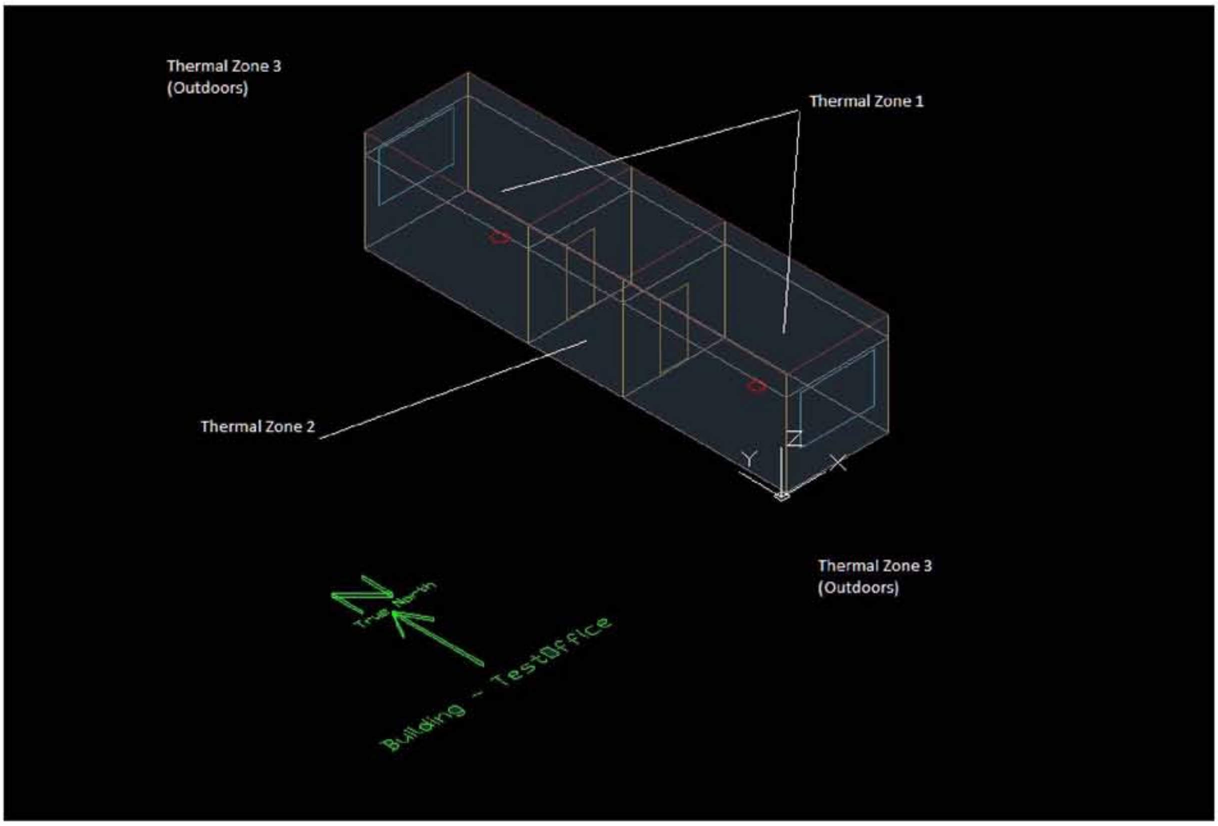


Figure 4.1: Thermal zones of the test office

- **Construction characteristics of the opaque building elements:**
  - **Interio Floor:**IntGypsum15mm,XPS20mm,Concrete2%Fe150mm,Carpet5mm
  - **Exterior Wall:**ExtGypsum15mm,XPS50mm,Brick90mm,Brick90mm,IntGypsum10mm
  - **Interior Wall:**IntGypsum15mm,XPS30mm,IntGypsum15mm
  - **Interior Ceiling:**Carpet5mm,Concrete2%Fe150mm,XPS20mm,IntGypsum15mm
  - **Exterior Window:**CLEAR 6mm,AIR 13mm,LoE CLEAR 6mm
  - **Suspended:**SuspendedCeiling10mm
  - **Interior Door:**Wood
  - **Exterior Blinds:**BLIND WITH MEDIUM REFLECTIVITY SLATS,CLEAR 6mm,AIR 13mm,LoE CLEAR 6mm

All the above are mentioned from the outside layer to the inside

– **Building use data:**A principle parameter of the analysis is the profile of the building use, such as the number of operating hours, the number of occupants, the number and type of lighting equipment and other equipment used.

  * The operating period of the building is from 9:00 to 17:00 seven days a week
  * Maximum Heating Supply Air Temperature:50 °C
  * Minimum Cooling Supply Air Temperature:13 °C
  * Illuminate Setpoint at First Reference Point: 500 lux
  * Illuminate Setpoint at Second Reference Point: 500 lux
  * Minimum Input Power Fraction For Continuous Dimming Control:0.15
  * Minimum Light Output Fraction For Continuous Dimming Control:0.05
  * Internal Heat Gains from the Electric Equipment :15 W/m^2
  * Internal Heat Gains from Lighting :16 W/m^2
  * Internal Heat Gains from the Occupants :0.1 W/Person
  * People per Zone Floor Area :0.1 Person/m^2

4.2.2 Steps and Results of Simulation

1. **Glazing Area in North Direction** In the first part of the optimizations the glazing area of the north facing facade is the parameter being optimized.

   The default glazing surface characteristics for the front panel of the window are:

   - **Thikness:**0.006m
   - **Solar Transimtance at Normal Incidence:**0.6
   - **Front Side Solar Reflectance at Normal Incidence:**0.17
   - **Back Side Solar Reflectance at Normal Incidence:**0.22
   - **Visible Transmitance at Normal Incidence:**0.84
   - **Front Side Visible Reflectance at Normal Incidence:**0.055
   - **Back Side Visible Reflectance at Normal Incidence:**0.078
   - **Infrared Transmitance at Normal Incidence:**0
   - **Front Side Infrared Hemispherical Emissivity:**0.84
   - **Back Side Infrared Hemispherical Emissivity:**0.1
   - **Conductivity:**0.9 W/mK

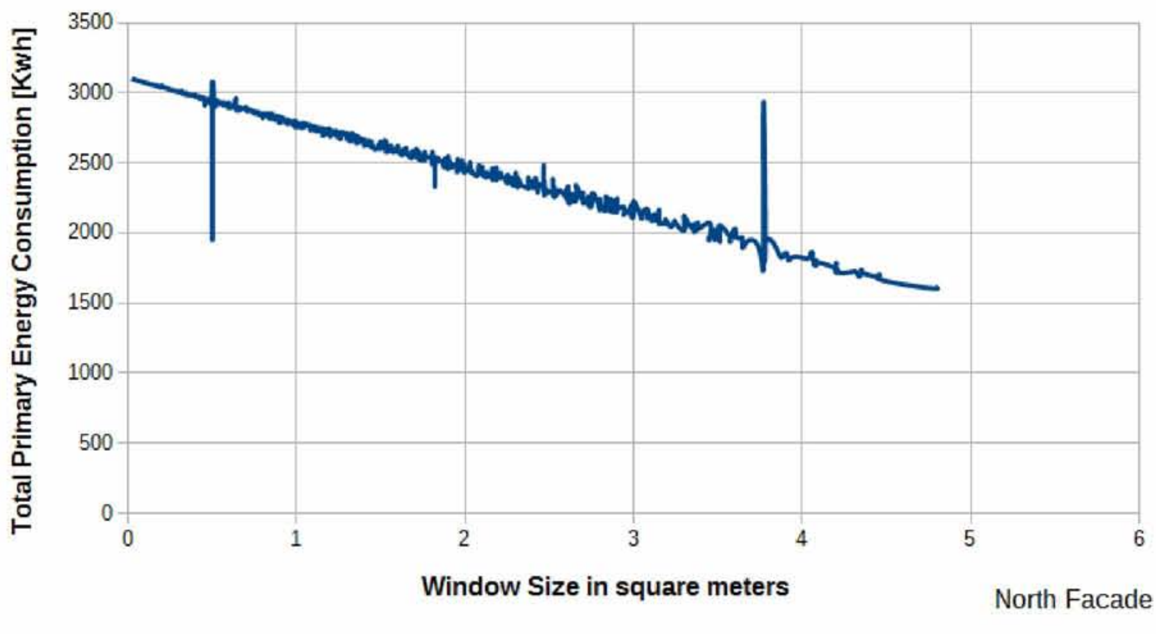
   The default glazing surface characteristics for the back panel of the window are:

   - **Thikness:**0.006m
   - **Solar Transimtance at Normal Incidence:**0.775
   - **Front Side Solar Reflectance at Normal Incidence:**0.071

- **Back Side Solar Reflectance at Normal Incidence:**0.071
- **Visible Transmitance at Normal Incidence:**0.881
- **Front Side Visible Reflectance at Normal Incidence:**0.08
- **Back Side Visible Reflectance at Normal Incidence:**0.08
- **Infrared Transmitance at Normal Incidence:**0
- **Front Side Infrared Hemispherical Emissivity:**0.84
- **Back Side Infrared Hemispherical Emissivity:**0.84
- **Conductivity:**0.9 W/mK

The gas that was used between the panels of the default window is Air with 0.0127 m of thickness and Thermal Transmitance 0.17 m^2K/W
During this simulation also the default External Blinds were present.

At first,the glazing area was simulated and the % of the area was tested between 10% and 80%.The area of the glazing surface that provided the least Primary Energy Consumption(Heating ,Cooling,Lighting) is 4.76 m^2 or 51.85% of the wall.The least Primary Energy Consumption(Heating ,Cooling,Lighting) in north direction is 1605.84 Kwh or 87.46 KW/m^2.



For northern orientation the solar heat gain coefficient (g-value) doesn't have significant impact because there is no direct sunlight entering the spaces from the glazing of this façade.
It is significant to highlight that for southern openings the most important factor is the g-value; low values contribute to low solar radiation transmitted through the glazing and the portion of absorbed energy that ends up supplying heat inside.

2. **Type of Glazing Optimization** Three different types of glazing surfaces were used in the simulation the optimum triplet of each is described in detail below:

- **Double Clear:**
  - **U-Factor:**2.7 W/m^2K
  - **Solar Heat Gain Coefficient:**0.71
  - **Visible Transmittance:**0.79
- **Double LowE:**
  - **U-Factor:**$1.5W/m^2K$
  - **Solar Heat Gain Coefficient:**0.37
  - **Visible Transmittance:**0.7
- **Double Solar Control:**
  - **U-Factor:**$1.63W/m^2K$
  - **Solar Heat Gain Coefficient:**0.79
  - **Visible Transmittance:**0.75

With the use of Double Clear glazing surface Total Primary Consumption Lighting Heating cooling is 1594.27 Kwh or 86.83 KW/m^2.
With the use of Double LowE glazing surface Total Primary Consumption Lighting Heating cooling is 1717.15 Kwh or 93.52 KW/m^2. With the use of Double Solar Control glazing surface Total Primary Consumption Lighting Heating cooling is 1631.45 Kwh or 88.85 KW/m^2.

3. **External Venetian Blinds Optimization** For each one of the aforementioned glazing types three different types of External Venetian Blinds were tested.These are:

   - External Venetian Blinds with Beaded Slats,
   - External Venetian Blinds with Dim-Out Slats and
   - External Venetian Blinds with Flat Slats

   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1576.98 Kwh or 85.92 KW/m^2.
   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1573.93 Kwh or 85.72 KW/m^2.
   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1572.81 Kwh or 85.66 KW/m^2.
   The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the

aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1722.83 Kwh or 93.83 KW/m^2.

The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1717.66 Kwh or 93.55 KW/m^2.

The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1715.46 Kwh or 93.43 KW/m^2.

The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1621.23 Kwh or 88.30 KW/m^2.

The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1617.66 Kwh or 88.10 KW/m^2.

The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1616.43 Kwh or 88.04 KW/m^2.

4. **Overhang Optimization** After we have applied the External Venetian Blinds to each different type of glazing we now focus on the Size and Angle of the overhang.Each overhang is installed 0.1 m above the window and its length is equal to the length of the window.Thereafter results of the application of overhang are described.

   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1540.45 Kwh or 83.90 KW/m^2.

   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1543.64 Kwh or 84.07 KW/m^2.

   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1539.36 Kwh or 83.43 KW/m^2.

   The optimum results for Double LowE glazing in combination with Exter-

nal Venetian Blinds with Beaded Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1539.36 Kwh or 83.43 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the North window has Tilt Angle from Window=180° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1717.66 Kwh or 93.55 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the North window has Tilt Angle from Window=180° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1715.46 Kwh or 93.43 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1573.67 Kwh or 85.71 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1570.54 Kwh or 85.54 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the North window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1568.80 Kwh or 85.44 KW/m^2.

5. **Fin Optimization** After we have applied the External Venetian Blinds and the Overhang to each different type of glazing we now focus on the Size and Angle of the Side Fins.Each fin is installed 0.1 m left and right from the window,0.05m above the top of the window and 0.1m below the the bottom of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1555.65 Kwh or 84.73 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1559.12 Kwh or 84.91 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting)

for the existing overhang characteristics is 1554.42 Kwh or 84.66 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1554.42 Kwh or 84.66 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1743.63 Kwh or 93.96 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1741.28 Kwh or 94.84 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1589.79 Kwh or 86.58 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1586.11 Kwh or 86.38 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the North window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1584.41 Kwh or 86.29 KW/m^2.

6. **Glazing Area in South Direction** In the following part of the optimizations the glazing area of the north facing facade is the parameter being optimized.

   The default glazing surface characteristics for the front panel of the window are:

   - **Thikness:**0.006m
   - **Solar Transimtance at Normal Incidence:**0.6
   - **Front Side Solar Reflectance at Normal Incidence:**0.17
   - **Back Side Solar Reflectance at Normal Incidence:**0.22
   - **Visible Transmitance at Normal Incidence:**0.84
   - **Front Side Visible Reflectance at Normal Incidence:**0.055
   - **Back Side Visible Reflectance at Normal Incidence:**0.078
   - **Infrared Transmitance at Normal Incidence:**0

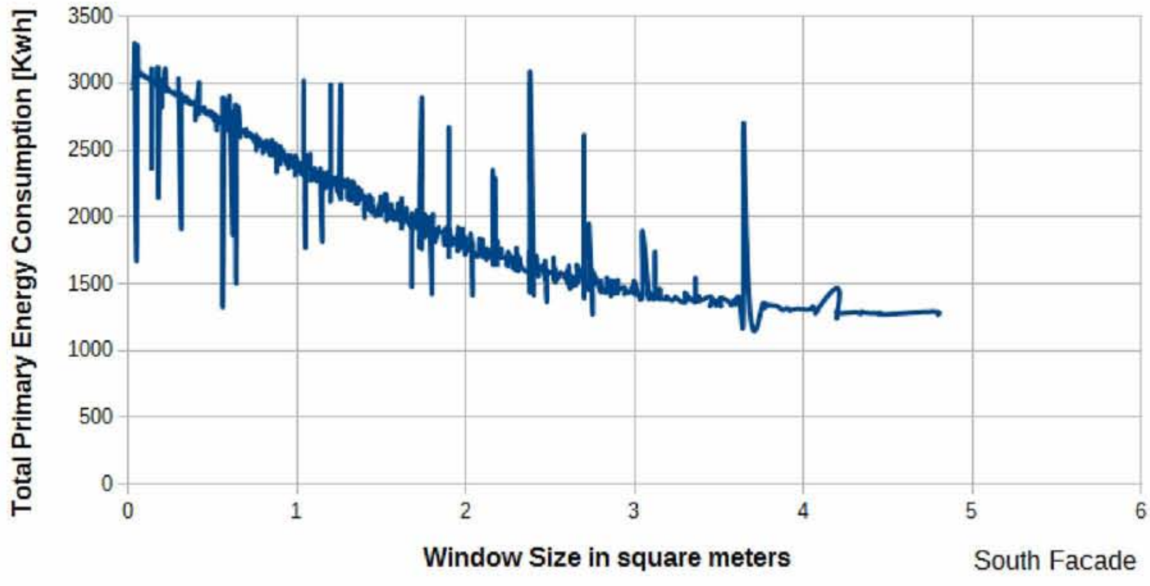
- **Front Side Infrared Hemispherical Emissivity:**0.84
- **Back Side Infrared Hemispherical Emissivity:**0.1
- **Conductivity:**0.9 W/mK

The default glazing surface characteristics for the back panel of the window are:

- **Thikness:**0.006m
- **Solar Transimtance at Normal Incidence:**0.775
- **Front Side Solar Reflectance at Normal Incidence:**0.071
- **Back Side Solar Reflectance at Normal Incidence:**0.071
- **Visible Transmitance at Normal Incidence:**0.881
- **Front Side Visible Reflectance at Normal Incidence:**0.08
- **Back Side Visible Reflectance at Normal Incidence:**0.08
- **Infrared Transmitance at Normal Incidence:**0
- **Front Side Infrared Hemispherical Emissivity:**0.84
- **Back Side Infrared Hemispherical Emissivity:**0.84
- **Conductivity:**0.9 W/mK

The gas that was used between the panels of the default window is Air with 0.0127 m of thickness and Thermal Transmitance 0.17 m^2K/W
During this simulation also the default External Blinds were present.

At first,the glazing area was simulated and the % of the area was tested between 10% and 80%.The area of the glazing surface that provided the least Primary Energy Consumption(Heating ,Cooling,Lighting) is 4.2 m^2 or 45.75% of the wall.The least Primary Energy Consumption(Heating ,Cooling,Lighting) in South direction is 1257.68 Kwh or 68.5 KW/m^2.



It is significant to highlight that for southern openings the most important factor is the g-value; low values contribute to low solar radiation transmitted through the glazing and the portion of absorbed energy that ends up supplying heat inside.

7. **Type of Glazing Optimization** Three different types of glazing surfaces were used in the simulation the optimum triplet of each is described in detail below:

   - **Double Clear:**
     - **U-Factor:**2.7 W/m^2K
     - **Solar Heat Gain Coefficient:**0.71
     - **Visible Transmittance:**0.79
   - **Double LowE:**
     - **U-Factor:**1.5W/m^2K
     - **Solar Heat Gain Coefficient:**0.37
     - **Visible Transmittance:**0.7
   - **Double Solar Control:**
     - **U-Factor:**1.63W/m^2K
     - **Solar Heat Gain Coefficient:**0.79
     - **Visible Transmittance:**0.75

   With the use of Double Clear glazing surface Total Primary Consumption Lighting Heating cooling is 1289.62 Kwh or 70.24 KW/m^2.
   With the use of Double LowE glazing surface Total Primary Consumption Lighting Heating cooling is 1270.70 Kwh or 69.21 KW/m^2. With the use of Double Solar Control glazing surface Total Primary Consumption Lighting Heating cooling is 1317.76 Kwh or 71.77 KW/m^2.

8. **External Venetian Blinds Optimization** For each one of the aforementioned glazing types three different types of External Venetian Blinds were tested.These are:

   - External Venetian Blinds with Beaded Slats,
   - External Venetian Blinds with Dim-Out Slats and
   - External Venetian Blinds with Flat Slats

   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1268.25 Kwh or 69.07 KW/m^2.
   The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1268.14 Kwh or 69.07 KW/m^2.

The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1268.05 Kwh or 69.06 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=105°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1229.12 Kwh or 66.94 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=105°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1227.92 Kwh or 66.88 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=105°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1227.42 Kwh or 66.85 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1310.27 Kwh or 71.36 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.073m,Slat Thickness=0.0025m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1310.79 Kwh or 71.39 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.06m,Slat Thickness=0.0075m and Slat Angle=100°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1310.27 Kwh or 71.36 KW/m^2.

9. **Overhang Optimization** After we have applied the External Venetian Blinds to each different type of glazing we now focus on the Size and Angle of the overhang.Each overhang is installed 0.1 m above the window and its length is equal to the length of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the South window has Tilt Angle from Window=65° and Depth=1.5m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1177.97 Kwh or 64.15 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the South window has Tilt Angle from Window=65° and Depth=1.5m.The To-

tal Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1177.33 Kwh or 64.12 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the South window has Tilt Angle from Window=65° and Depth=1.5m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1177.03 Kwh or 64.10 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the South window has Tilt Angle from Window=60° and Depth=1.5m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1193.25 Kwh or 64.99 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the South window has Tilt Angle from Window=60° and Depth=1.5m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1191.22 Kwh or 64.88 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the South window has Tilt Angle from Window=60° and Depth=1.5m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1190.52 Kwh or 64.84 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the South window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1718.03 Kwh or 93.57 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the South window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1189.43 Kwh or 64.78 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the South window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1191.04 Kwh or 64.87 KW/m^2.

10. **Fin Optimization** After we have applied the External Venetian Blinds and the Overhang to each different type of glazing we now focus on the Size and Angle of the Side Fins.Each fin is installed 0.1 m left and right from the window,0.05m above the top of the window and 0.1m below the the bottom of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1161.63 Kwh or 63.26 KW/m^2.
The optimum results for Double Clear glazing in combination with Exter-

nal Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1160.46 Kwh or 63.20 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1160.01 Kwh or 63.18 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1210.97 Kwh or 65.95 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1208.60 Kwh or 65.82 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1190.23 Kwh or 63.19 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 2056.84 Kwh or 112.02 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1118.59 Kwh or 64.59 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the South window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1188.07 Kwh or 64.7 KW/m^2.

Concluding the optimized building primary energy consumption occurs for glazing type Double Clear with Flat External Venetian Slats and overhang and it Total Primary Energy Consumption (Heating,Cooling,Lighting) reaches 1160.01 Kwh 63.18 KW/m^2.

11. **Glazing Area in East Direction** In the next part of the optimizations the glazing area of the East facing facade is the parameter being optimized.

The default glazing surface characteristics for the front panel of the window are:

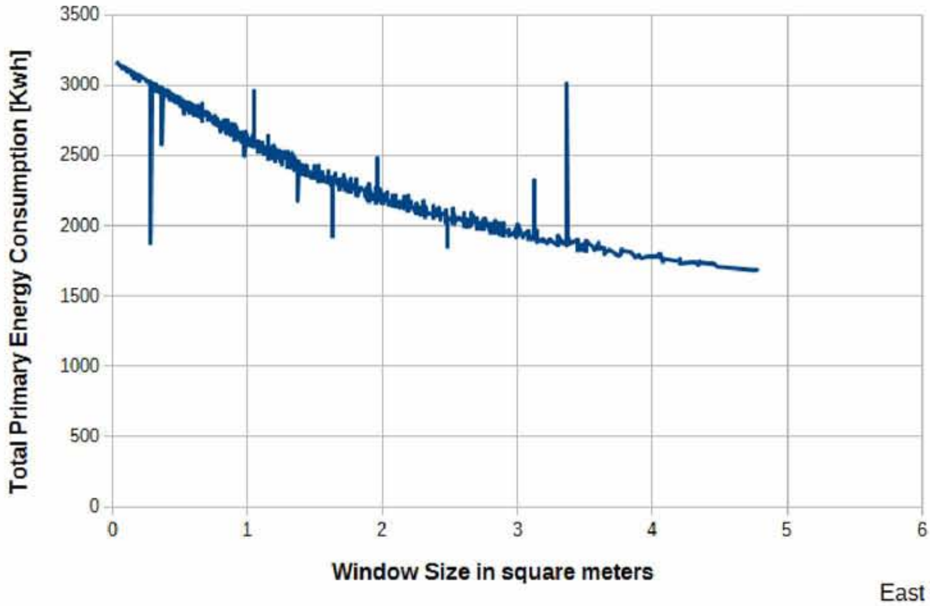
- **Thikness:**0.006m
- **Solar Transimtance at Normal Incidence:**0.6
- **Front Side Solar Reflectance at Normal Incidence:**0.17
- **Back Side Solar Reflectance at Normal Incidence:**0.22
- **Visible Transmitance at Normal Incidence:**0.84
- **Front Side Visible Reflectance at Normal Incidence:**0.055
- **Back Side Visible Reflectance at Normal Incidence:**0.078
- **Infrared Transmitance at Normal Incidence:**0
- **Front Side Infrared Hemispherical Emissivity:**0.84
- **Back Side Infrared Hemispherical Emissivity:**0.1
- **Conductivity:**0.9 W/mK

The default glazing surface characteristics for the back panel of the window are:

- **Thikness:**0.006m
- **Solar Transimtance at Normal Incidence:**0.775
- **Front Side Solar Reflectance at Normal Incidence:**0.071
- **Back Side Solar Reflectance at Normal Incidence:**0.071
- **Visible Transmitance at Normal Incidence:**0.881
- **Front Side Visible Reflectance at Normal Incidence:**0.08
- **Back Side Visible Reflectance at Normal Incidence:**0.08
- **Infrared Transmitance at Normal Incidence:**0
- **Front Side Infrared Hemispherical Emissivity:**0.84
- **Back Side Infrared Hemispherical Emissivity:**0.84
- **Conductivity:**0.9 W/mK

The gas that was used between the panels of the default window is Air with 0.0127 m of thickness and Thermal Transmitance 0.17 m^2K/W
During this simulation also the default External Blinds were present.

At first,the glazing area was simulated and the % of the area was tested between 10% and 80%.The area of the glazing surface that provided the least Primary Energy Consumption(Heating ,Cooling,Lighting) is 4.76 m^2 or 51.85% of the wall.The least Primary Energy Consumption(Heating ,Cooling,Lighting) in East direction is 1684.49 Kwh or 91.74 KW/m^2.



East Facade

It is significant to highlight that for southern openings the most important factor is the g-value; low values contribute to low solar radiation transmitted through the glazing and the portion of absorbed energy that ends up supplying heat inside.

12. **Type of Glazing Optimization** Three different types of glazing surfaces were used in the simulation the optimum triplet of each is described in detail below:

    - **Double Clear:**
      - **U-Factor:**2.7 W/m^2K
      - **Solar Heat Gain Coefficient:**0.71
      - **Visible Transmittance:**0.79
    - **Double LowE:**
      - **U-Factor:**$1.5W/m^2K$
      - **Solar Heat Gain Coefficient:**0.37
      - **Visible Transmittance:**0.7
    - **Double Solar Control:**
      - **U-Factor:**$1.63W/m^2K$
      - **Solar Heat Gain Coefficient:**0.79
      - **Visible Transmittance:**0.75

    With the use of Double Clear glazing surface Total Primary Consumption Lighting Heating cooling is 1732.24 Kwh or 94.34 KW/m^2.
    With the use of Double LowE glazing surface Total Primary Consumption Lighting Heating cooling is 1686.82 Kwh or 91.87 KW/m^2. With the use of Double Solar Control glazing surface Total Primary Consumption Lighting Heating cooling is 1757.27 Kwh or 95.71 KW/m^2.

13. **External Venetian Blinds Optimization** For each one of the aforementioned glazing types three different types of External Venetian Blinds were tested.These are:

    - External Venetian Blinds with Beaded Slats,
    - External Venetian Blinds with Dim-Out Slats and
    - External Venetian Blinds with Flat Slats

    The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1701.61 Kwh or 92.68 KW/m^2.
    The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1700.57 Kwh or 92.62 KW/m^2.
    The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1700.17 Kwh or 92.60 KW/m^2.
    The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1675.04 Kwh or 91.23 KW/m^2.
    The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1672.86 Kwh or 91.11 KW/m^2.
    The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1671.93 Kwh or 91.06 KW/m^2.
    The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1749.12 Kwh or 95.26 KW/m^2.
    The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aforementioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1746.05 Kwh or 95.1 KW/m^2.

The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1744.89 Kwh or 95.03 KW/m^2.

14. **Overhang Optimization** After we have applied the External Venetian Blinds to each different type of glazing we now focus on the Size and Angle of the overhang.Each overhang is installed 0.1 m above the window and its length is equal to the length of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the East window has Tilt Angle from Window=160° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1650.42 Kwh or 89.89 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the East window has Tilt Angle from Window=160° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 2138.52 Kwh or 116.47 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the East window has Tilt Angle from Window=160° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1648 Kwh or 89.76 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the East window has Tilt Angle from Window=90° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1674.21 Kwh or 91.18 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the East window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1620.45 Kwh or 88.25 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the East window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1619.47 Kwh or 88.20 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the East window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1718.03 Kwh or 93.57 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the East window has Tilt Angle from Window=175° and Depth=0.8m.The

Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1714.88 Kwh or 93.40 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the East window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1713.76 Kwh or 93.34 KW/m^2.

15. **Fin Optimization** After we have applied the External Venetian Blinds and the Overhang to each different type of glazing we now focus on the Size and Angle of the Side Fins.Each fin is installed 0.1 m left and right from the window,0.05m above the top of the window and 0.1m below the the bottom of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1630.40 Kwh or 80.80 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1628.22 Kwh or 88.68 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1627.49 Kwh or 88.64 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1658.06 Kwh or 90.30 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1616.03 Kwh or 88.01 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1614.95 Kwh or 87.96 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1717.66 Kwh or 93.55 KW/m^2.
The optimum results for Double Solar Control glazing in combination with Ex-

ternal Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1714.52 Kwh or 93.38 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the East window have Tilt Angle from Window=150 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1713.37 Kwh or 93.32 KW/m^2.

Concluding the optimized building primary energy consumption occurs for glazing type Double LowE with Flat External Venetian Slats, Overhang and Side Fins with Total Primary Energy Consumption (Heating,Cooling,Lighting) reaches 1614.03 Kwh 88.01 KW/m^2.

16. **Glazing Area in West Direction** In the next part of the optimizations the glazing area of the East facing facade is the parameter being optimized.

    The default glazing surface characteristics for the front panel of the window are:

    - **Thikness:**0.006m
    - **Solar Transimtance at Normal Incidence:**0.6
    - **Front Side Solar Reflectance at Normal Incidence:**0.17
    - **Back Side Solar Reflectance at Normal Incidence:**0.22
    - **Visible Transmitance at Normal Incidence:**0.84
    - **Front Side Visible Reflectance at Normal Incidence:**0.055
    - **Back Side Visible Reflectance at Normal Incidence:**0.078
    - **Infrared Transmitance at Normal Incidence:**0
    - **Front Side Infrared Hemispherical Emissivity:**0.84
    - **Back Side Infrared Hemispherical Emissivity:**0.1
    - **Conductivity:**0.9 W/mK

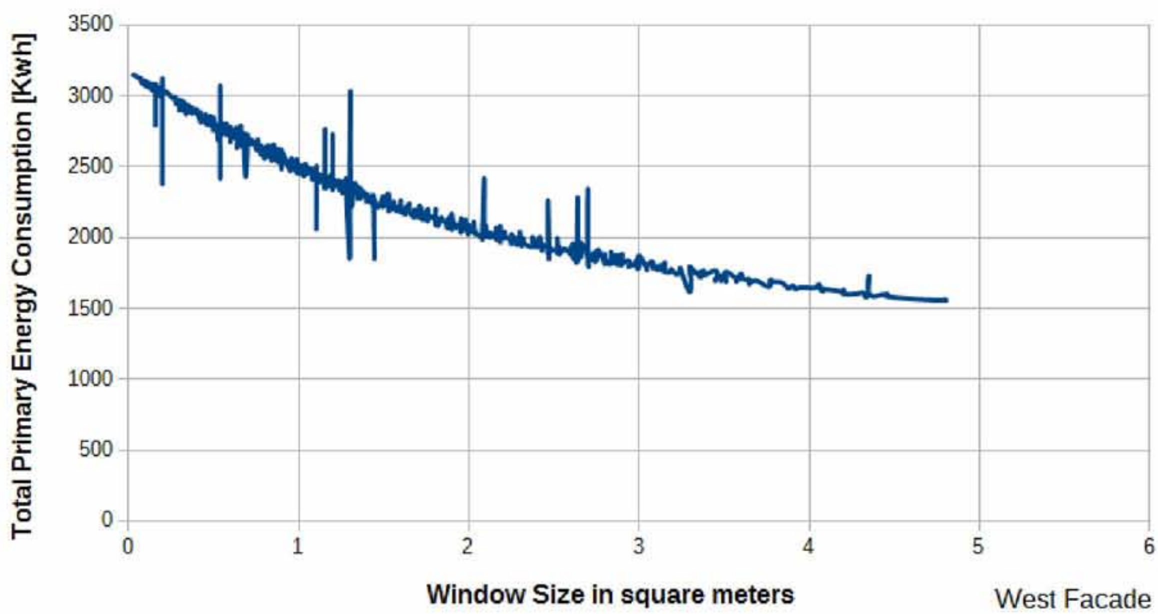
    The default glazing surface characteristics for the back panel of the window are:

    - **Thikness:**0.006m
    - **Solar Transimtance at Normal Incidence:**0.775
    - **Front Side Solar Reflectance at Normal Incidence:**0.071
    - **Back Side Solar Reflectance at Normal Incidence:**0.071
    - **Visible Transmitance at Normal Incidence:**0.881
    - **Front Side Visible Reflectance at Normal Incidence:**0.08
    - **Back Side Visible Reflectance at Normal Incidence:**0.08
    - **Infrared Transmitance at Normal Incidence:**0

- **Front Side Infrared Hemispherical Emissivity:**0.84
- **Back Side Infrared Hemispherical Emissivity:**0.84
- **Conductivity:**0.9 W/mK

The gas that was used between the panels of the default window is Air with 0.0127 m of thickness and Thermal Transmitance 0.17 m^2K/W
During this simulation also the default External Blinds were present.

At first,the glazing area was simulated and the % of the area was tested between 10% and 80%.The area of the glazing surface that provided the least Primary Energy Consumption(Heating ,Cooling,Lighting) is 4.76 m^2 or 51.85% of the wall.The least Primary Energy Consumption(Heating ,Cooling,Lighting) in East direction is 1557.12 Kwh or 84.10 KW/m^2.



It is significant to highlight that for southern openings the most important factor is the g-value; low values contribute to low solar radiation transmitted through the glazing and the portion of absorbed energy that ends up supplying heat inside.

17. **Type of Glazing Optimization** Three different types of glazing surfaces were used in the simulation the optimum triplet of each is described in detail below:

    - **Double Clear:**
      - **U-Factor:**2.7 W/m^2K
      - **Solar Heat Gain Coefficient:**0.71
      - **Visible Transmittance:**0.79
    - **Double LowE:**

- **U-Factor:**$1.5W/m^2K$
- **Solar Heat Gain Coefficient:**0.37
- **Visible Transmittance:**0.7

- **Double Solar Control:**
  - **U-Factor:**$1.63W/m^2K$
  - **Solar Heat Gain Coefficient:**0.79
  - **Visible Transmittance:**0.75

With the use of Double Clear glazing surface Total Primary Consumption Lighting Heating cooling is 1591.63 Kwh or 89.69 KW/m^2.
With the use of Double LowE glazing surface Total Primary Consumption Lighting Heating cooling is 1546.34 Kwh or 84.22 KW/m^2. With the use of Double Solar Control glazing surface Total Primary Consumption Lighting Heating cooling is 1617.55 Kwh or 88.10 KW/m^2.

18. **External Venetian Blinds Optimization** For each one of the aforementioned glazing types three different types of External Venetian Blinds were tested.These are:

- External Venetian Blinds with Beaded Slats,
- External Venetian Blinds with Dim-Out Slats and
- External Venetian Blinds with Flat Slats

The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1567.59 Kwh or 85.38 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1566.39 Kwh or 85.13 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1565.86 Kwh or 85.28 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.08m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1537.33 Kwh or 83.73 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=45°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 2484.27 Kwh or 135.3 KW/m^2.

The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.06m,Slat Thickness=0.0025m and Slat Angle=175°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1600.93 Kwh or 87.19 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1600.85 Kwh or 87.19 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when Slat Width = 0.093m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) is 1609.85 Kwh or 87.62 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when Slat Width = 0.1m,Slat Thickness=0.0025m and Slat Angle=80°.As a result of the application of the aformentioned combination the Total Primary Energy Consumption (Heating,Cooling,Lighting) 1608.78 Kwh or 87.62 KW/m^2.

19. **Overhang Optimization** After we have applied the External Venetian Blinds to each different type of glazing we now focus on the Size and Angle of the overhang.Each overhang is installed 0.1 m above the window and its length is equal to the length of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the West window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1464.16 Kwh or 79.74 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the West window has Tilt Angle from Window=125° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1462.32 Kwh or 79.64 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the West window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1466.70 Kwh or 79.88 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the West window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1487.22 Kwh or 81.00 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the West window has Tilt Angle from Window=20° and Depth=0.9m.The To-

tal Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1880.50 Kwh or 102.42 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the West window has Tilt Angle from Window=10° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 2769.85 Kwh or 150.86 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats happens when the overhand of the West window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1582.75 Kwh or 86.20 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats happens when the overhand of the West window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1579.66 Kwh or 86.03 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats happens when the overhand of the West window has Tilt Angle from Window=175° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1578.25 Kwh or 86.24 KW/m^2.

20. **Fin Optimization** After we have applied the External Venetian Blinds and the Overhang to each different type of glazing we now focus on the Size and Angle of the Side Fins.Each fin is installed 0.1 m left and right from the window,0.05m above the top of the window and 0.1m below the the bottom of the window.Thereafter results of the application of overhang are described.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1458.65 Kwh or 79.44 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150° and Depth=1m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1512.97 Kwh or 82.40 KW/m^2.
The optimum results for Double Clear glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1456.09 Kwh or 79.30 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1494.87 Kwh or 81.41 KW/m^2.
The optimum results for Double LowE glazing in combination with Exter-

nal Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1906.67 Kwh or 103.89 KW/m^2.
The optimum results for Double LowE glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=80 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 2781.74 Kwh or 151.5 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Beaded Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1597.32 Kwh or 87.00 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Dim-Out Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1594.22 Kwh or 86.83 KW/m^2.
The optimum results for Double Solar Control glazing in combination with External Venetian Blinds with Flat Slats and the optimum Overhang happens when the fins of the West window have Tilt Angle from Window=150 ° and Depth=0.8m.The Total Primary Energy Consumption (Heating,Cooling,Lighting) for the existing overhang characteristics is 1592.80 Kwh or 86.75 KW/m^2.

Concluding the optimized building primary energy consumption occurs for glazing type Double Clear with Flat External Venetian Slats, Overhang and Side Fins with Total Primary Energy Consumption (Heating,Cooling,Lighting) reaches 1456.09 Kwh or 79.30 KW/m^2.

The optimum scenarion is the one that our test office faces South direction with Side Fins,Overhang,Double Clear windows and Flat External Venetian Blinds.The Total Primary Energy Consumption (Heating,Cooling,Lighting) reaches 1160.01 Kwh or 61.18 KW/m^2.

4.3 Summary

The fourth chapter was related to the simulation results and their analysis. The building and climatic parameters which were used for the building simulation were presented. Specifically the type of each building element (floor,interior ceiling, exterior ceiling,interior and exterior walls,interior door,suspended ceiling and exterior blinds), the glazing properties, the optimum glazing area and orientation and all the relevant parameters were presented.The answer to the research problem which is the potential energy saving of buildings by the application of appropriate type and percentage of glazing,optimum angle orientaion,external venetian blinds characteristics and best shading systems(overhangs and fins).

Chapter 5

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